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# (54) Microwave plane antenna

(57) A microwave plane antenna (FAT) which includes rows of antenna elements ($ATE_1$-$ATE_n$) of cranked micro-strip lines (ASL) and a power supply circuit (PSC) of strip lines (SSL) branched for connection of the elements to provide an elevational setting for the pointing direction of the array, is such that the strip lines to the respective elements are varied in length to vary the phases to the elements, so that the main beam direction can be set in azimuth.

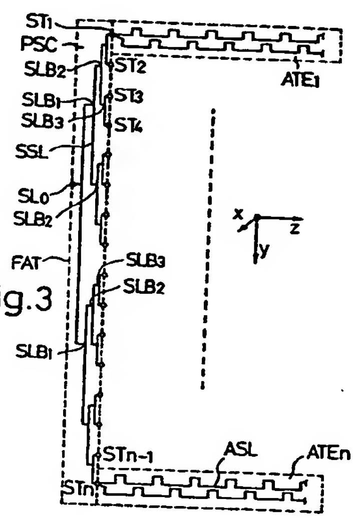


Fig.3

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Fig.1

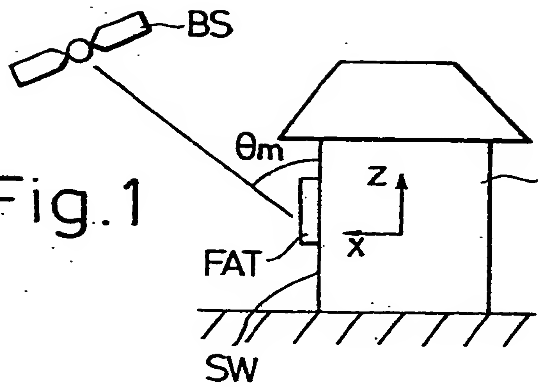



Fig. 2

(a)

(b)

(c)

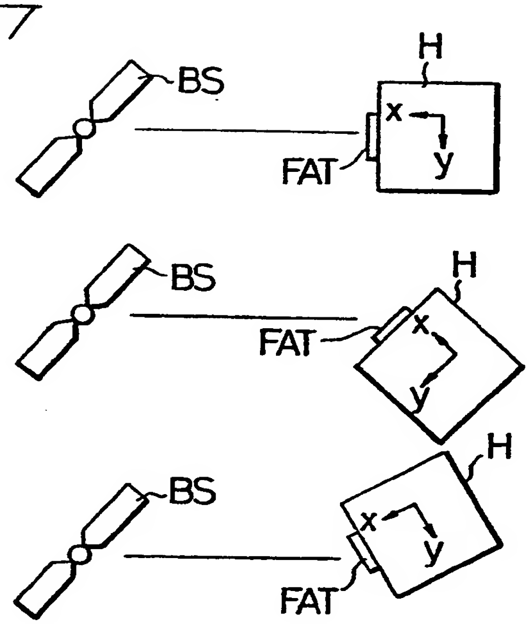
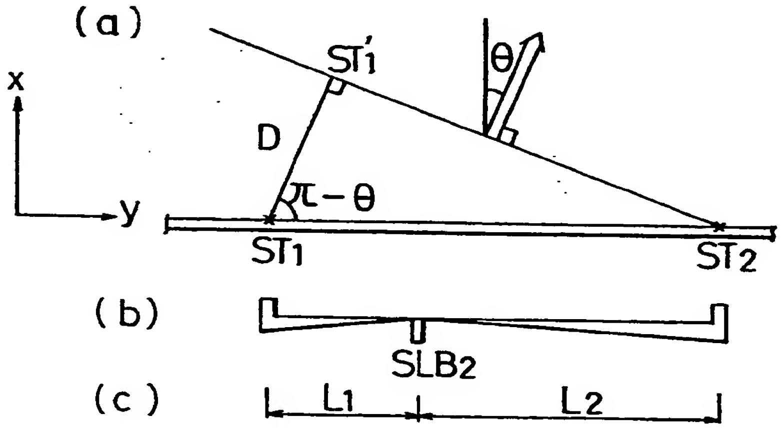



Fig. 4

(a)

(b)

(c)



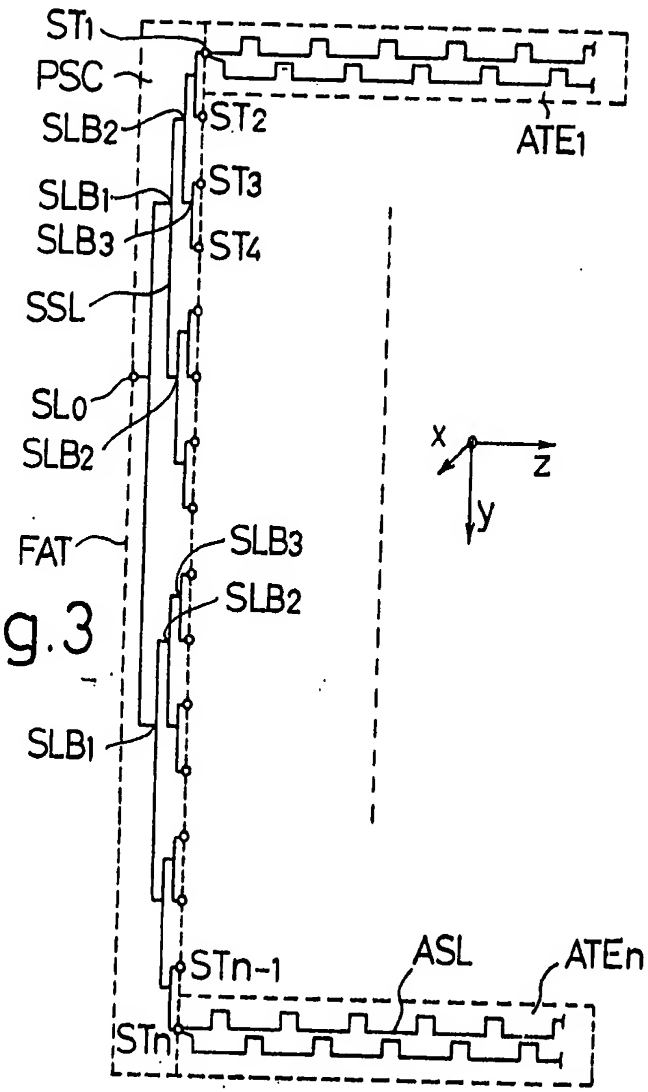

ST1
PSC
SLB2
SLB1
SLB3
SSL
SL0
SLB2
FAT
SLB1
ST2
ST3
ST4
ATE1
x
z
y
SLB3
SLB2
STn-1
ASL
ATEn
STn

Fig.3

Fig.7

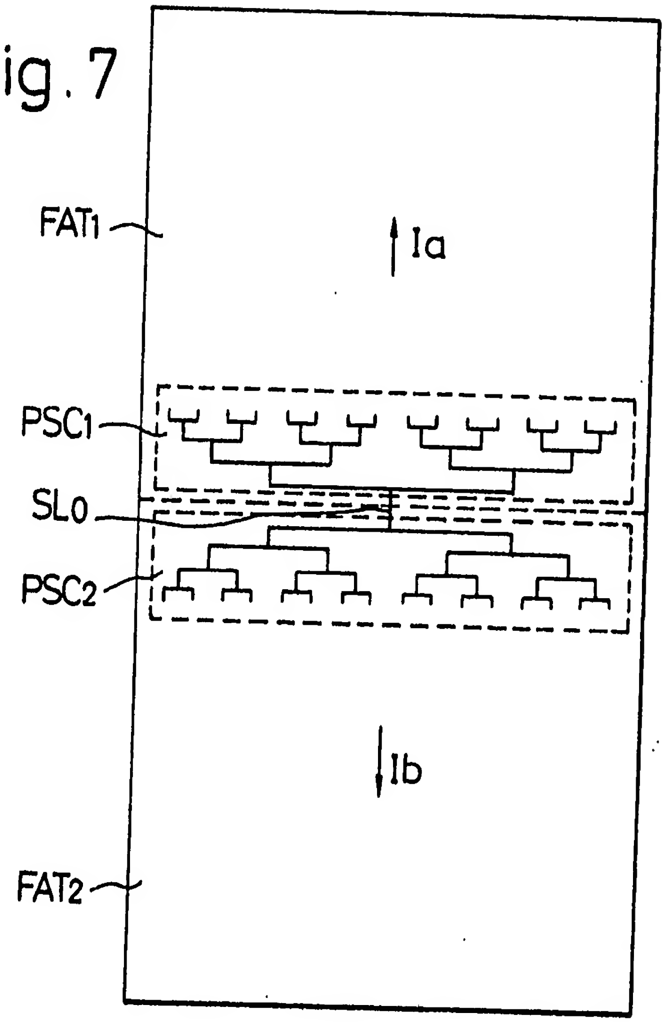

FAT1
Ia
PSC1
SL0
PSC2
Ib
FAT2

Fig. 5

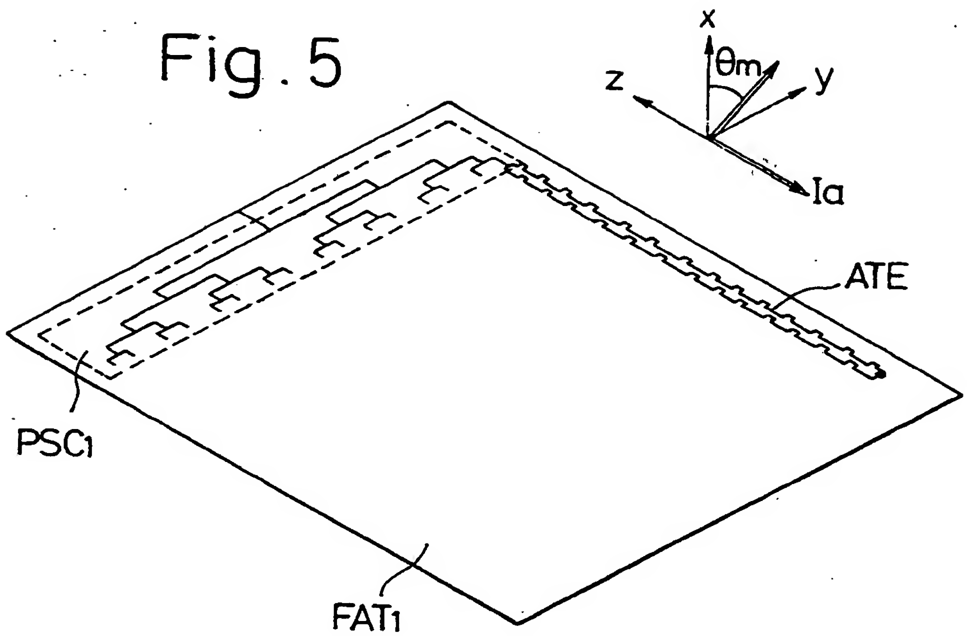
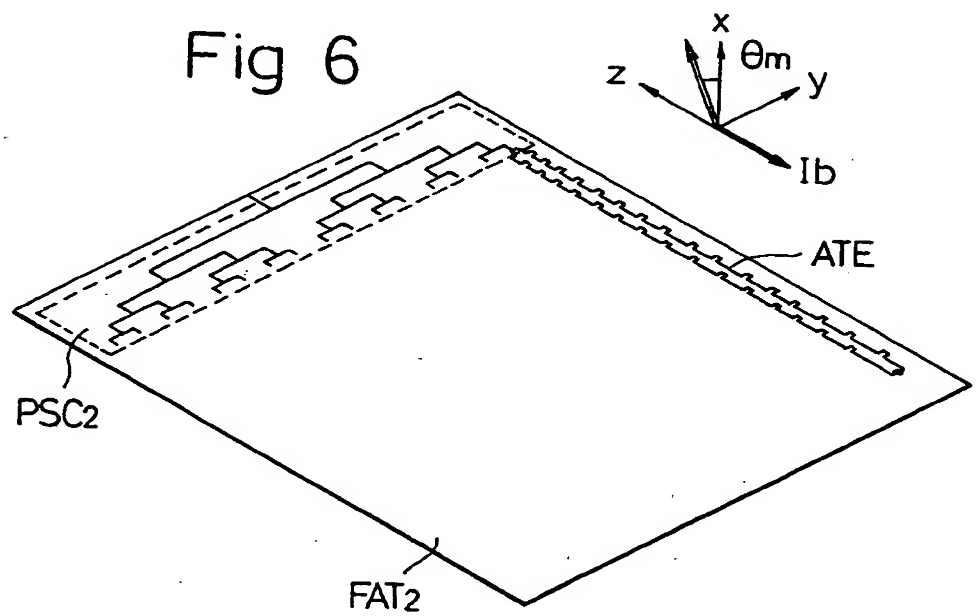



Fig 6



SPECIFICATION

**Microwave plane antenna**

This invention relates to a microwave plane antenna for receiving circularly polarized waves.

The microwave plane antenna of the type referred to is effective to receive circularly polarized waves which are transmitted as carried on SHF band, in particular 12 GHz band, from a geostationary broadcasting satellite launched into cosmic space 36,000 Km high from the earth.

Geostationary satellite broadcastings have been put into practice in recent years. The electro-magnetic waves transmitted from the satellite are circularly polarized waves and, specifically, such waves transmitted from a Japanese broadcasting satellite launched above the equator and received in Japan are righthanded.

Antennas generally used by listeners for receiving such circularly polarized waves are parabolic antennas erected on the roof or the like position of house buildings. However, the parabolic antenna has been involving such problems that its member configuration and mounting structure are complicated to render its manufacturing cost to be rather high, it is susceptible to strong wind to easily fall due to its bulky structure so that an additional means for stably supporting the antenna will be necessary, and supporting means further requires such troublesome work as a fixing to the antenna of reinforcing pole members forming a major part of the supporting means, which work may happen to result even in a higher cost than that of the antenna itself, rendering thus the parabolic antenna to be expensive.

In attempt to eliminate these problems on use of the parabolic antenna, there has been suggested in Japanese Patent Appln. Laid-Open Publication No. 99803/1982 (corresponding to U.S. Patent No. 4,475,107 or to German Offenlegungsschrift No. 3149200) a plane antenna attempted to be flattened in the entire configuration, so that the antenna can be simplified in the structure to render it inexpensive and made mountable directly on a wall surface of house buildings, eliminating the necessity of any additional supporting means to reduce required cost for the mounting.

More in detail, this plane antenna is a cranked micro-strip line antenna, which comprises antenna elements arranged in a plurality of rows, each of which elements consisting of a pair of micro-strip line conductors made to run as cranked so that a so-called one-dimensional array antenna of traveling wave type having a frequency characteristic and directivity determined by the manner in which the micro-strip line conductors are cranked, i.e., their cranking cycle. Assuming here that the micro-strip lines are of a width minimized to infinity and connected to a power source for a uniform flow of traveling-wave current through the lines, then the directive characteristics in x-z plane of the antenna can be calculated by obtaining conditions for radiating the circularly polarized waves in the main beam direction $\theta_m$, the radiating conditions themselves for the circularly polarized wave being able to be expressed by following equations:

$$b + (1 - \eta\cos\theta_m)\, 2a = \lambda g \left\{ 1 \mp \frac{1}{\pi}\mathrm{Tan}^{-1}(\sin\theta_m/1 - \eta\cos\theta_m)\right\} \quad \ldots (1)$$

$$b + (1 - \eta\cos\theta_m)\, c = \lambda g \left\{ 1 \pm \frac{1}{\pi}\mathrm{Tan}^{-1}(\sin\theta_m/1 - \eta\cos\theta_m)\right\} \quad \ldots (2)$$

where $\theta_m$ denotes the main beam direction, "a", "b" and "c" are the lengths at leg side, lateral side and central side, respectively, of such crank shape of the micro-strip line as shown in FIG. 4 of the Japanese Publication, $\eta$ is the wavelength shortening coefficient of the micro-strip line, $\lambda g$ is the line wavelength of the micro-strip line, the upper "−" sign of the double signs in the equation (1) or "+" sign in the other equation (2) denotes lefthanded circularly polarized waves, the lower "+" sign of the double signs in the equation (1) or "−" sign in the equation (2) denotes the righthanded circularly polarized waves, "x" axis is the one vertical to the plane antenna, "y" axis is the one in the width direction of the antenna elements, and "z" axis is in the lengthwise direction of the elements.

In the equations (1) and (2), values of $\theta_m$ and "b" properly selected and inserted into the equations will also determine values of "a" and "c", whereby the side length of the crank shape can be determined, and a micro-strip line can be formed. A plurality of such micro-strip lines are provided in pairs, spatial phases of the micro-strip lines in each pair are made mutually different, and the cranked portions of adjacent ones of the micro-strip lines are positioned to be staggered for restraining the grating lobe of the radiation beam and sharpening its directivity. A plurality of rows of the antenna elements respectively comprising the pair of the micro-strip lines are provided on one surface of an insulating substrate of a Teflon R.T.M. glass fiber, polyethylene or the like and provided over the other surface with an earthing conductor. Provided to one end side of the antenna element rows is a power supply circuit which includes strip line conductors branched into a so-called tournament connection to supply an electric power to the respective antenna elements parallelly in the same amplitude and phase, while a termination resistor is inserted at the other ends of the antenna elements.

In the foregoing cranked micro-strip line antenna, the main beam direction $\theta_m$ can be varied by changing the dimensions of the crank shape in the micro-strip lines or, in other words, the antenna can be provided with any desired directivity. As shown in FIG. 1, therefore, a micro-strip line antenna FAT mounted on a southward wall SW of a house building H can set the main beam direction $\theta_m$ in the x-z plane with respect to a geostationary broadcasting satellite BS for achieving the maximum gain of signal reception. The main beam direction $\theta_m$, that is, the incident angle of signal waves transmittted from the satellite depends on the terrestrial latitude of the

antenna location, which is in the range of, for example, about 30° to 50° in Japan.

In the plane antenna FAT of the cranked micro-strip lines, the micro-strips are perpendicular to the y axis in the x-y plane so that, when signal waves from the satellite BS are incident on the antenna FAT in the x axis direction and are thus vertical to the plane antenna as shown in FIG. 2(a), the antenna can attain a predetermined signal reception gain. When the signal waves from the satellite BS are not perpendicular to the plane antenna FAT in the x-y plane but are angled with respect to the x axis as shown in FIG. 2(b) or FIG. 2(c), however, there has arisen a problem that the signal reception gain drops remarkably. In other words, the main beam direction can be properly set in the x-z plane by changing the crank shape of the micro-strip lines but not in the x-y plane, whereby the main beam direction is not allowed to be settable in three-dimensional sense. For this reason, the plane antenna FAT has such a problem that, when the wall SW perpendicular to the incident signal wave is unavailable as in the case of FIG. 2(b) or (c), it has been unable to raise the signal reception gain.

To raise the signal reception gain, on the other hand, it may be effective to increase the number of micro-strip lines in the plane antenna and to extend them longer, but this measure is disadvantageous in narrowing the frequency band in the plane antenna of the foregoing arrangement. The suggestion of the above Japanese Publication has been an attempt to increase the number of the strip lines without narrowing the frequency band by means of a provision of a pair of the micro-strip line antennas in parallel relation to each other, which suggestion has caused, however, still another problem to arise in that, since the pair of micro-strip line antennas are parallel in a direction perpendicular to the longitudinal direction of the micro-strip lines as shown in FIGS. 14 and 15 of the Publication, the strip lines forming a common power supply circuit for the both antennas as connected between their input sides are required to run longer enough for increasing the power loss in the circuit itself, rendering it substantially impossible to increase the signal reception gain. More particularly, the strip lines of the power supply circuit are generally provided on an insulating substrate by means of a printing, in which event the power loss in the strip lines of the power supply circuit is determined depending on their length along the y axis, so as to be about 3 dB/m in the case of a power supply circuit for the parallel plane antennas of a standard size. On the other hand, the signal reception gain obtained by the parallel plane antennas is increased by 3 dB with a doubled reception area in the case of such standard size as above. This increment in the signal reception gain obtained by the paired parallel provision of the antennas, however, has to be substantially cancelled by the loss in the power supply circuit, and the suggested measure has been still defective in this respect.

A primary aim of the present invention is, therefore, to provided a plane antenna which can set the main beam direction of the antenna, i.e., the incident angle of signal waves from the geostationary broadcasting satellite, both in the x-y and x-z planes, so as to allow it possible to set the incident angle of the received signal waves freely in three-dimensional zone, and can restrain any loss in the power supply circuit even in a parallel provision of the paired plane micro-strip line antennas without narrowing the frequency band, whereby the total signal reception gain of the plane antenna can be raised to be closer to signal reception efficiency of the parabolic antenna known to achieve a signal reception gain of 65%.

According to the present invention, this aim can be realized by providing a microwave plane antenna comprising a plurality of pairs of antenna elements respectively consisting of a pair of micro-strip lines of a conductor arranged in rows and respectively cranked at many portions thereof while having the cranked portions of each line staggered with respect to those of the other line, a power supply circuit of strip conductor lines branched for a tournament type connection of the antenna elements at their one end side, and a termination resistor connected to the other ends of the antenna elements, wherein the strip lines of the power supply circuit are made different in the length leading from a main power supply end of the circuit to power receiving ends of the antenna elements so that the main beam inclination can be set in a plane including the plane of the antenna and perpendicular to an axis in lengthwise direction of the antenna elements; or a plane antenna comprising a pair of plane antenna parts respectively including the antenna elements arranged in rows, and a pair of the power supply circuits for the paired antenna parts and connected together at their main power supply ends, wherein the paired plane antenna parts are provided in the axial symmetry with respect to a line perpendicular to the longitudinal direction of the antenna elements, so that the power supply circuits of the both antenna parts can be closely opposed to each other, and main beam directions of the antenna elements in the both plane antenna parts can be made consistent to each other.

Other aims and advantages of the present invention shall be made clear in the following description of the invention detailed with reference to preferred embodiments shown in accompanying drawings, in which:—

FIGURE 1 is a diagram for explaining the incident angle of signal waves transmitted from a geostationary broadcasting satellite to a plane antenna in the x-z plane, that is, a main beam direction of the plane antenna in the x-z plane;

FIG. 2 shows diagrams for explaining the incident angle of the signal waves to the plane antenna in the x-y plane, that is, a deviation of the main beam direction within the x-y plane of the antenna;

FIG. 3 is a plan view showing a pattern of a major part in an embodiment of a microwave plane antenna of cranked micro-strip lines according to the present invention;

FIG. 4 shows diagrammatically relationships between the main beam inclination and a strip line of the power supply circuit in the plane antenna of FIG. 3;

FIG. 5 is a perspective view showing a pattern of one of the paired micro-strip antenna parts of the microwave plane antenna in another embodiment of

the present invention;

FIG. 6 is a perspective view showing a pattern of the other micro-strip antenna parts in the embodiment of FIG. 5; and

FIG. 7 shows in a plan view detailed pattern of the power supply circuit in the embodiment of FIG. 5.

While the present invention shall now be described with reference to the preferred embodiments shown in the drawings, it should be understood that the intention is not to limit the invention only to the particular embodiments shown but rather to cover all alterations, modifications and equivalent arrangements possible within the scope of appended claims.

Referring to FIG. 3, there is shown a microwave plane antenna FAT of cranked micro-strip lines in an embodiment of the present invention, in which a plurality of antenna elements $ATE_1$ to $ATE_n$ are arranged substantially in parallel rows. Each of the antenna elements $ATE_1$ to $ATE_n$ comprises a pair of micro-strip lines ASL of a strip conductor cranked cyclically repetitively, and the pair of the strip lines ASL are so arranged as to have cranked portions of each line respectively staggered with respect to those of the other line, so that a spatial phase difference will be provided for suppressing the grating lobe of the radiation beam and sharpening its directivity. As a result, there can be provided a traveling-wave antenna of single dimensional array which has a frequency characteristic and directivity determined by the manner in which the strip lines are cranked, i.e., cranking cycle of the micro-strip lines ASL. These antenna elements are provided on one surface of an insulating substrate having over the other surface an earthing conductor.

The antenna elements $ATE_1$ to $ATE_n$ are connected at their one end side to a power supply circuit PSC which comprises strip conductor line SSL running from a main power supply end $SL_o$ to an end of each element while being branched to form a tournament type connection line. In the illustrated embodiment, more particularly, the strip line SSL is so branched as to connect the main power end $SL_o$ through first to third tournament branches $SLB_1$ to $SLB_3$ to respective power receiving ends $ST_1$ to $ST_n$ of the antenna elements $ATE_1$ to $ATE_n$, so that the elements will be supplied with an external electric power through the power supply circuit PSC.

Branched sections of the strip line SSL of the power supply circuit PSC are respectively made to have a length sequentially varied while running from the main power supply end $SL_o$ to the power receiving ends $ST_1$ to $ST_n$ of the antenna elements $ATE_1$ to $ATE_n$. More particularly, in the illustrated embodiment of FIG. 3, the main power supply end $SL_o$ is positioned to be biased towards the side of the first antenna element $ATE_1$ from the center of the antenna elements $ATE_1$ to $ATE_n$ and from the center of a first tournament stage section of the line SSL. Similarly, each point of the first to third tournament branches $SLB_1$ to $SLB_3$ is off-centered in each of subsequent stage sections towards the side of the first antenna element $ATE_1$. Accordingly, branched parts of the strip line SSL in the respective stage sections and on both sides of the point of the branches $SLB_1$ - $SLB_3$ are made to be gradually larger in the length at one of the branched parts particularly on the side of the element $ATE_n$ than the other part on the side of the element $ATE_1$. Referring to this, for example, at the last stage sections of the branches $SLB_3$ with reference to FIGS. 4(b) and 4(c), a branched part length $L_2$ for supplying the power to the second antenna element $ATE_2$ is larger than the other branched part length $L_1$ to the first antenna element $ATE_1$. This branching manner causes a time lag to occur in required time for supplying the power to the second antenna element $ATE_2$ with respect to that for the first antenna element $ATE_1$. As shown in FIG. 4(a), this time lag is equivalent to a shift of the power receiving end $ST_1$ of the first antenna element $ATE_1$ to a point $ST_1'$, which shift causing the equiphase surfaces of the both elements to be inclined, and it is meant that the main beam direction is inclined by an angle θ with respect to the x axis in the x-y plane. Conditions for this inclination of the main beam direction in the x-y plane may be expressed by equations as follows:

$$\beta L_1 + k(L_1+L_2).\cos(\pi-\theta) = \beta L_2 + 2n\pi$$

$$\beta(L_2-L_1) = k(L_1+L_2).\cos(\pi-\theta) - 2n\pi \quad (n = o, \pm 1, \ldots.)$$

wherein β is a line phase constant ($2\pi/\lambda g$), k is a spatial phase constant ($2\pi/\lambda o$), λg is a line wavelength, and λo is a spatial wavelength. Accordingly, when the branched strip line part length $L_1$ for the first antenna element $ATE_1$ and the other branched strip line part length $L_2$ for the second antenna element $ATE_1$ are determined, the angle θ will be determined. That is, the main beam direction in the x-y plane can be suitably set by properly setting the entire power supplying strip line lengths for the respective antenna elements $ATE_1$ to $ATE_n$. In other words, the inclination of the main beam direction can be optimumly set within the plane including that of the plane antenna and perpendicular to the lengthwise axis of the antenna elements, for achieving the maximum signal reception gain. As a result, any reduction in the reception gain can be suppressed even when the signal waves from the broadcasting satellite BS are not perpendicular to the plan antenna in the x-y plane as shown in FIG. 2(b) or 2(c), and the setting of the main beam direction in both of the x-z and x-y planes can be made possible, that is, the directivity of the plane antenna can be set three-dimensionally, so as to remarkably increase the signal reception gain of the plane antenna, rendering it to be utilizable in expanded area.

In the above embodiment, the length of the branched parts of the strip line SSL of the power supply circuit PSC has been described as being increased gradually to be longer as the respective sections of the line SSL in each tournament stage approach the last antenna element $ATE_n$, specifically at the part on the side of the last element $ATE_n$. However, this increasing may be made in reverse direction, so as to be increased gradually from the antenna element $ATE_n$ toward the antenna element $ATE_1$, in accordance with the incident angle of the received waves. Further, the number into which the strip line SSL is branched, that is, the number of the tournament stages, may be properly increased depending on an increase in the number of the antenna elements.

Referring next to FIGS. 5 to 7, there is shown a microwave plane antenna in another embodiment of the present invention, in which a pair of plane antennas $FAT_1$ and $FAT_2$ are provided in the axial symmetry with respect to a line vertical to the lengthwise direction of the antenna elements, that is, to the z axis. The paired plane antennas $FAT_1$ and $FAT_2$ include a pair of the power supply circuits $PSC_1$ and $PSC_2$ and a pair of rows of the antenna elements ATE (only one of which element is shown in FIG. 5 or 6) respectively forming the micro-strip line antenna line antenna. In this case, each of the power supply circuits $PSC_1$ and $PSC_2$ disposed in the axial symmetry includes conductive strip line branched to form an ordinary tournament type connection without such improvement as in the power supply circuit PSC of FIG. 3, for supplying a power to the respective antenna elements in the both antennas $FAT_1$ and $FAT_2$ at the same amplitude and phase and in parallel relation.

In the plane antenna $FAT_1$, as shown in FIG. 5, the rows of the antenna elements ATE are arranged so that the main beam direction is inclined in the x-z plane by an angle $\theta_m$ with respect to the x axis in a direction in which a traveling wave current $I_a$ flows, so that the plane antenna $FAT_1$ will form a so-called advancing wave side looking antenna. On the other hand, in the plane antenna $FAT_2$ as shown in FIG. 6, the antenna elements ATE are arranged so that the main beam direction will be inclined also in the x-z plane by the angle $\theta_m$ with respect to the x axis but in a direction opposite to a direction in which a travelling wave current $I_b$ flows, so that this plane antenna $FAT_2$ will form a so-called retrograding wave side looking antenna. Since the main beam directions of the both plane antennas $FAT_1$ and $FAT_2$ are inclined mutually in opposite directions by the same angle, their main beam directions, i.e., their directivities are made to coincide with each other in their composite state, and the directivity is not ill influenced by the increase of the rows of the antenna elements to be doubled for raising the signal reception gain.

Further, in the embodiment of FIGS. 5 to 7, in particular, the paired power supply circuits $PSC_1$ and $PSC_2$ are coupled to each other at their common main power supply end $SL_o$ as disposed to oppose in close proximity to each other in the axial symmetry, so that the length of the strip line forming the main power supply end $SL_o$ for the both power supply circuits $PSC_1$ and $PSC_2$ can be minimized and thus the loss of the power supply circuits $PSC_1$ and $PSC_2$ can be made negligibly small. According to the present embodiment, the signal reception gain has been shown experimentally to have been increased by about 3 dB, whereby the plane antenna can be remarkably improved in the signal reception gain for allowing its utility to be widely practiced.

In the present invention, further, a variety of design modifications may be made. Just as an example, the arrangement explained in connection with FIGS. 3 and 4 may be combined with the arrangement of FIGS. 5 to 7 to provide a plane antenna which attains a signal reception gain improved to a large extent as a whole, so that the plane antenna can be further improved in the signal reception efficiency to be closer to that of the parabolic antenna.

CLAIMS

1. A microwave plane antenna comprising a plurality of antenna elements arranged in rows, each of said antenna elements consisting of a pair of micro-strip lines of a conductor having cranks respectively disposed to be staggered between said pair of lines, and a power supply circuit connected to one end side of side antenna elements, said circuit consisting of conductor strip lines branched to form a tournament type connection and to have respectively a different length of connection between a main power supply end of the circuit and each power receiving end of the respective antenna elements, said different length of said branched strip lines taking place within a place including said plane antenna and perpendicular to an axis of the antenna in lengthwise direction of the antenna elements and setting the inclination of main beam direction of the antenna in said plane.

2. A plane antenna according to claim 1, wherein branch points in said tournament connection of said power supply circuit are biased toward one end side of said plurality of antenna elements so that said different length of said branched strip lines of the circuit takes place sequentially from said one end side of the antenna elements.

3. A plane antenna according to claim 1, wherein equiphase surface of adjacent ones of said antenna elements is inclined so that said main beam direction is inclined in a plane including an axis perpendicular to said plane antenna and an axis in widthwise direction of the antenna elements.

4. A microwave plane antenna including a pair of plane antenna parts for receiving circularly polarized waves, said plane antenna parts comprising respectively a plurality of antenna elements arranged in rows, each of said antenna elements consisting of a pair of mirco-strip lines of a conductor having cranks respectively disposed to be staggered in mutual relation between said pair of lines, and a power supply circuit connected to one end side of said antenna elements and consisting of conductor strip lines branched to form a tournament connection between a main power supply end to each power receiving end of the respective antenna elements, wherein said power supply circuits of said pair of plane antenna parts are arranged to closely oppose each other as disposed in the axial symmetry with respect to a line perpendicular to an axis in lengthwise direction of the antenna elements, and said antenna elements in the pair of the plane antenna parts define a composite main beam directed to a predetermined direction.

5. A plane antenna according to claim 4, wherein said composite main beam direction is of a first main beam direction defined by one of said pair of plane antenna parts to be inclined by an angle in a direction in which a travelling wave current flows in a plane including an axis perpendicular to said plane antenna and an axis in lengthwise direction of the antenna elements, and a second main beam direction defined by the other plane antenna part to be inclined by an angle corresponding to said angle of said first main beam direction but in a direction opposite to said

traveling wave current flowing direction in said plane including said axes.

6. A microwave plane antenna substantially as described herein with reference to the drawings.

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